Course in

Practical Electricity

National Electric Light
Association

$F = \frac{M_1 M_2}{D^2}$

Rules Governing Award

of the

Frank W. Smith Educational Prize

of the

National Electric Light Association

MR. FRANK W. SMITH, Past President of the Association, offers annually a prize of $100.00 in gold, open for competition to members of the Association who are subscribers to any of the Educational Courses of the Association, and who qualify under the following rules.

This prize is to be awarded annually at each National Convention of the Association to the subscriber who has qualified under the following rules and who, in the judgment of a majority of the members of the Educational Committee present at a meeting at which this award is decided, has received the most tangible benefits from any of the courses, such benefits to be enumerated by the subscriber in a statement submitted setting forth in detail in what manner and to what extent the student or company has benefited by the course.

1. The subscriber must be in the employ of a company, firm or individual, which is a member of the Association at the time of completing the course and at the time the prize is awarded. **He must also hold an individual membership in the Association at the time of completing the course and at the time the prize is awarded, in one of the following classes:**

B—Officers or employes of regular Public Service companies or individuals engaged in producing and supplying electrical energy for light, heat, or power for public use.

E—Officers or employes of companies engaged in the manufacture of electrical apparatus or equipment for the production of electrical energy.

G—Officers or employes of companies of electrical jobbers, contractors, dealers, electrical or mechanical engineers, publishers, associations, or other corporations or individuals who are interested in advancing the use of electrical energy.

2. The subscriber must have completed his course with an average grade of not less than 90%.

3. The subscriber completing his course during the **year ending March 1st** is eligible to file a statement in competition for the prize to be awarded at the following National Convention. The time for filing statements **closes April 15th.** The statement must bear the endorsement of an elective executive officer of the company, firm, or individual by whom the subscriber is employed. This statement must set forth in detail the circumstances entitling the subscriber to the award, including such facts as increased amount of work accomplished by reason of having taken the course, increased responsibilities assumed or promotions received as a result of the course, increase in salary or income resulting from the study of the course, any saving to the company or suggestions adopted by the company which were made by him, any betterment in the Company's relations with the public inaugurated by the subscriber, or any other facts for submission to the judges, which in the judgment of the subscriber may be evidence of the tangible benefits received by him from the course in which he enrolled and which he completed.

The winner of the prize will have endorsed on his certificate "Winner of the Frank W. Smith Educational Prize" with the date of the award and the signatures of the President of the Association and of the Chairman of the Educational Committee.

The Committee strongly urges every subscriber, who is not already a member, to join the Association, not only for the purpose of competing for this prize but for many other advantages of membership. Success in any industry demands the most reliable and latest information, and the best manner of keeping up with the rapid strides of our industry and obtaining this information is by joining the National Electric Light Association.

For application blank and further information as to membership, address the National Electric Light Association, 29 West 39th St., New York City.

Statements in competition for the Frank W. Smith Prize must be received by Fred R. Jenkins, Chairman, Educational Committee, 72 W. Adams St., Chicago, before April 15th.

[redacted]

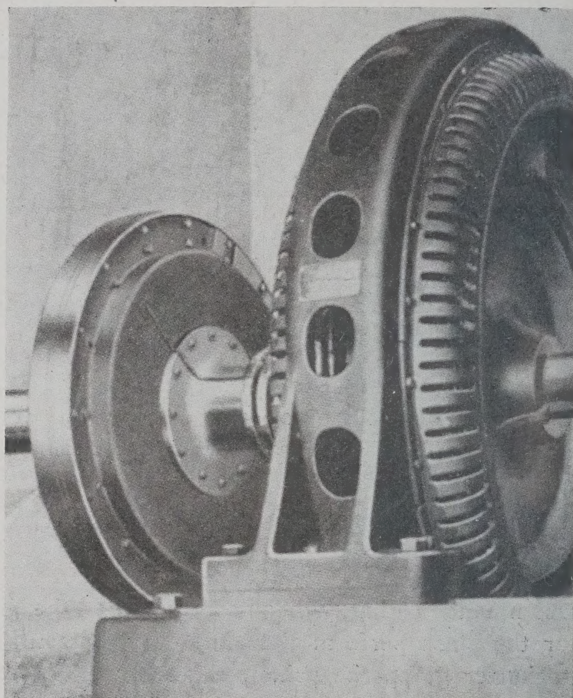
INTRODUCTION

The importance of the study of magnetism as a foundation for the further study of electricity cannot be overestimated, as practically every piece of electrical apparatus depends upon magnetism for its operation.

It is advisable for the student to read, reread, and study carefully the matter presented in this lesson, because an understanding of this subject is absolutely necessary before the following lessons can be understood.

The lessons are arranged in a logical order and each requires careful reading and study.

It is recommended that, whenever possible, the individual students or the class perform the simple experiments outlined in order to better grasp the principles involved.



A Sixty Inch Electro-Magnetic Clutch Connecting a 500 H. P. Synchronous Motor to the Main Shaft in a Flour Mill.

NATIONAL ELECTRIC LIGHT ASSOCIATION
COURSE IN PRACTICAL ELECTRICITY
LESSON I—MAGNETISM

The Natural Magnet. At least 2,500 and possibly 4,000 years ago it was discovered that a certain stone had the property of attracting to it small particles of iron. This stone was named "magnet" because the best quality of it was found in the province of Magnesia, in Asia Minor. It was what we now know as the magnetic oxide of iron, or magnetite, often spoken of as the lodestone. This discovery was the first step in what is now electrical science.

It was soon discovered that pieces of steel attracted by the lodestone, became magnets themselves and would attract other pieces of iron. These were the first artificial magnets.

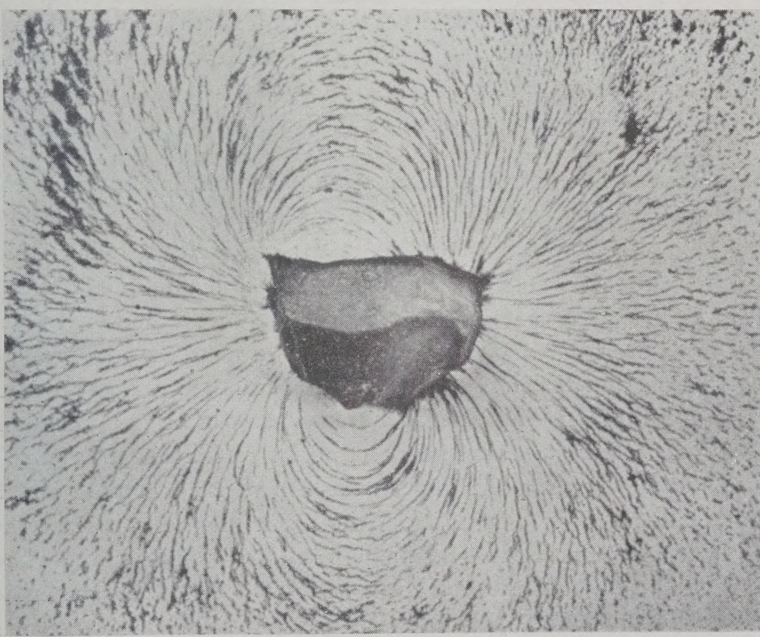


Figure 1—A Piece of Magnetic Iron Ore and the Magnetic Field Around it, Shown with Iron Filings.

The First Compass. It is generally believed that the Chinese discovered, about 2000 B. C., that a piece of lodestone suspended so as to be free to swing would set itself in a north and south direction, thus acting as a compass. The compass was not generally used, however, until about 1200 A. D.

The fact that the compass-needle places itself in a certain position shows that the earth acts like a large magnet. It has its north and south poles, the north pole being in the vicinity of Baffins Bay and the south pole on the opposite side of the earth.

At most places on the earth's surface, the compass does not point towards the Geographic North Pole, as the magnetic north pole and the Geographic North Pole do not coincide, and therefore a correction must be made to the compass reading in order to find the true north. In San Francisco the compass points east of north 17 degrees, in Chicago east of north 2 degrees 30 minutes, in New York 10 degrees west of north. This relation is not constant and it is necessary to re-determine the amount of deviation from time to time.

Naming the Poles. The end of the compass-needle pointing towards the north is called the **North-Seeking Pole,** while the end pointing south is called the **South-Seeking Pole.** Briefly, they are called the North Pole and the South Pole. This may lead to some confusion, unless care is taken to get the distinction between the magnetic pole near the Geographic North Pole and the pole that points to the north magnetic pole. They are in reality opposite in character, as can be easily shown. **Like poles repel** and **unlike poles attract**; that is, two north poles or two south poles repel each other, a north pole and a south pole attract. Therefore, if the north magnetic pole of the earth attracts the north-seeking pole of the compass, one must be a north pole and the other a south pole. All poles the same as the **north-seeking pole** are called **north-poles,** and all poles the same as the **south-seeking pole** are called **south-poles.**

Artificial Magnets. All magnets, other than the lodestone, are called artificial magnets. The most common of these are the so-called **Permanent-Magnets,** which are pieces of hard steel that have been magnetized and have retained a large amount of magnetism. The common bar and horse-shoe magnets are good examples.

Magnetic Field. If a compass needle is brought near a magnet, the compass is affected, showing that, surrounding the magnet, there is a space, or field, in which magnetism is present. This is called the magnetic field. If this space around the magnet is explored with a compass, or, if a plate of glass is placed above the magnet and iron filings sprinkled upon the plate, it will be found that the magnetic force acts along lines extending from pole to pole of the magnet, shaped and arranged about as shown in Figures 1, 2 and 3. These lines are called **Lines** of **Force.** They are lines along which magnetic force acts. No actual line exists but it is imaginary, the same as the line of sight, a line along which we see. Magnet strength is measured and stated in number of lines of froce per unit area. This an arbitrary unit but serves well the purposes of design.

Magnetic Materials. Materials that are good conductors of lines of force are called magnetic materials, such as iron and steel, while materials that are poor conductors of magnetism are called non-magnetic materials, such as copper, zinc, glass, etc. The materials of the first class are attracted by the magnet, while the latter are not affected or may be repelled. If a piece of iron is placed in the magnetic field shown in Figure 1, more lines of force will pass through the iron than passed through the air at that point, showing that iron is a better conductor of magnetism. Iron may be several hundred times as good a conductor of lines of force as air.

Bar and Horse-Shoe Magnets. If two identical bars of steel are made into magnets, one in bar shape and one in a horse-shoe shape, the horse-shoe magnet will have the greater number of lines of force and will be able to lift the greater weight, because the lines of force have nearly a complete path

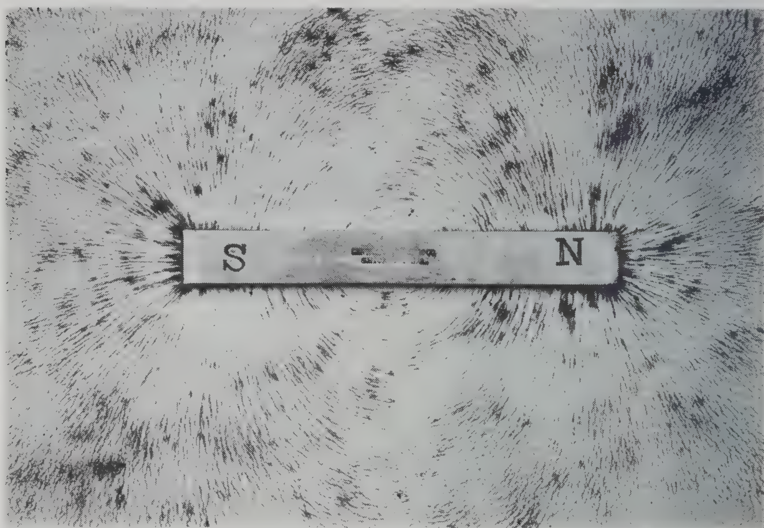


Figure 2—A Bar Magnet and the Magnetic Field About It.

of iron, whereas, with the bar magnet, a large part of the path is through air, and air is a poor conductor of magnetism. Magnets should be made with as short a path in air as possible. Permanent magnets will retain their strength better if they are provided with a keeper; that is, a piece of soft iron to be placed across the poles when the magnet is not in use.

Compound Magnets. Where permanent magnets of great strength are desired it is best to make up the magnet of several like magnets with like poles together. This combination is called a compound magnet, and gives much greater strength than could be obtained from a single magnet of the same size. A compound magnet is shown in Figure 4.

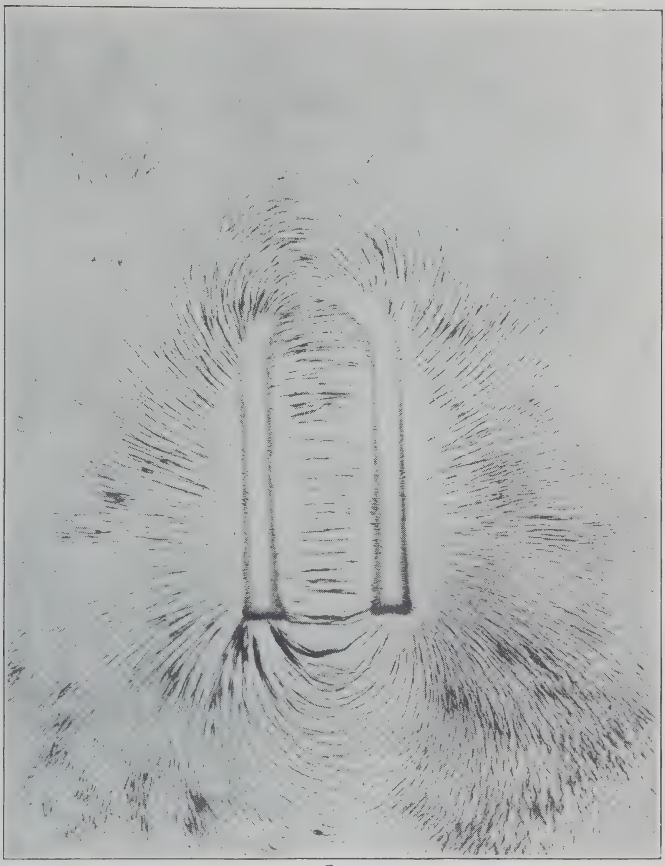


Figure 3—The Magnetic Field About a Permanent Horse-Shoe Magnet. A Piece of White Cardboard Rests Upon the Magnet and Iron Filings Were Sprinkled Over the Cardboard. Note the Direction of the Lines of Force, as Shown by the Iron Filings

Theory of Magnetism. It is not definitely known just what magnetism is, but there have been many theories advanced. The theory that is quite generally accepted is that every piece of magnetic material is made up of an infinite number of small magnets; that is, each molecule* of the material

*A molecule is a small particle of matter, made up of still smaller particles called atoms. Atoms are made up of electrical charges, called electrons.

is a small magnet with north and south poles. When the material is not magnetized, these molecules are arranged in groups forming closed magnetic circuits, as represented in Figure 5, in such a way that no magnetism is apparent outside of the

Figure 4—Two Permanent Magnets with Like Poles Together, Lifting a Load of Iron Filings. Note the Direction of the Lines of Force as Shown by the Iron Filings

bar. When a magnetizing force is applied, it is believed that these modecules rearrange themselves as shown in Figure 6, with like poles pointing in the same direction, thus giving outside evidence of magnetism. If the magnetizing force is removed,

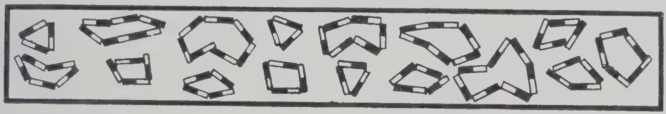


Figure 5—Illustrating the Positions of Molecules in an Unmagnetized Bar. Black End Represents the North Pole of Each Molecule

many of the molecules return to their original positions, and the magnetism of the bar is not so great. If a permanent magnet is struck with a hammer, it will lose some of its magnetism, as the blow has helped some of the molecules to return to their original positions. Permanent magnets should therefore be handled carefully in order to have them retain their strength.

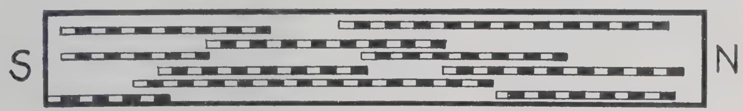


Figure 6—Showing the Arrangement of Molecules after Magnetization

If a magnetized needle, shown in Figure 7, be broken into several parts, each part will be found to have a north and a south pole. This shows that the lines of force are continuous throughout the bar and do not start from one end and terminate at the other. Direction is given to lines of force, as indicated

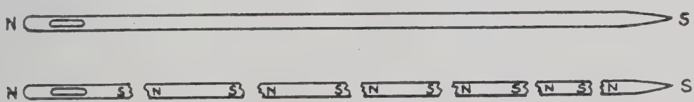


Figure 7—A Magnetized Needle, Before and After Breaking

by the compass needle; that is, if a compass needle is placed in front of the north pole of a magnet the needle points away from the pole and the lines of force are considered as leaving the north pole and entering the south pole as indicated in Figure 8.

Retentivity. Magnetic materials differ greatly in the amount of magnetism they will retain; that is, they differ in their **Retentivity.** If a bar of soft or mild steel is strongly magnetized, it will make a stronger magnet, while the magnetizing force is on, than will a bar of steel, but the instant the magnetizing force is removed, the soft steel will lose practically all of its magnetism, while the bar of hard steel will retain a relatively large amount. Soft steel, therefore, cannot be used to make permanent magnets. Hard steel is always used.

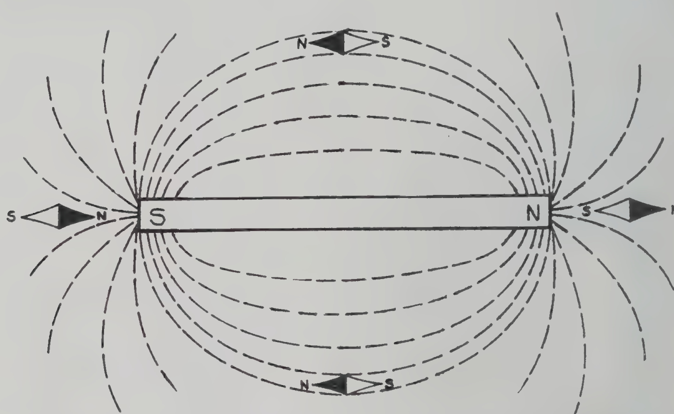


Figure 8—Diagram Showing Position of Compass Needle and Direction of Lines of Force

Effect of Heat on Magnetism. If a piece of steel is heated to red heat, the steel will not be acted upon by a magnet; that is, it becomes non-magnetic. The theory is that when heated the molecules are in rapid motion and can no longer be arranged with their like poles in the same direction. If a permanent magnet is heated to a red heat, it will lose its magnetism.

Aging of Magnets. Where magnets are to be used for electrical instruments or other purposes for which it is necessary that their strength remain constant, the magnets are given an aging treatment. That is, they are treated so that

only a small part of their original magnetism remains, usually between 5 and 10 per cent. They will remain more nearly of constant strength with a small amount of magnetism than they will with a larger amount. There are several aging treatments. One is to subject the magnet to a reverse magnetism, while another is a heat treatment, such as a steam bath or a hot oil bath.

Making Permanent Magnets. Permanent magnets of little strength can be made by applying the steel to a permanent magnet. Stronger magnets are made by subjecting the steel, which has been previously properly tempered, to a strong magnetic field, by placing the steel within a strong magnet coil or by placing it across the poles of an electro-magnet as shown in Figure 9.

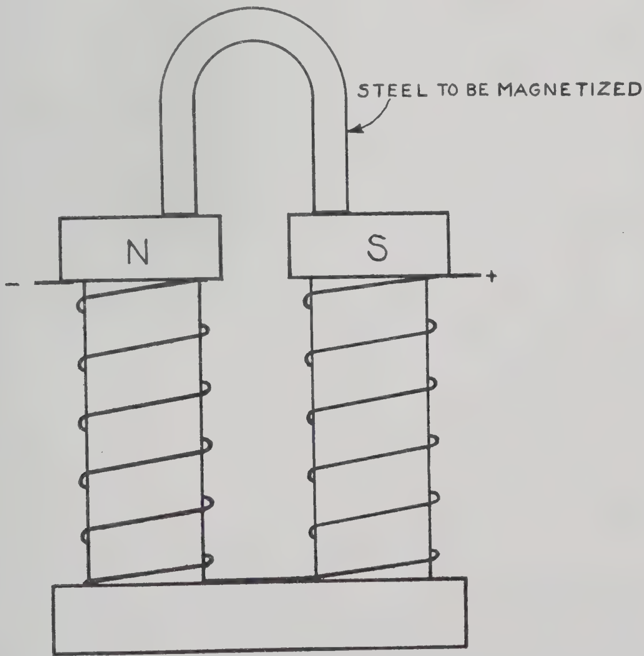


Figure 9—Method of Magnetizing Steel. A Strong Electro-Magnet with Steel to be Magnetized

Uses of Permanent Magnets. Permanent magnets are quite generally used in very practical ways, such as for small lifting work, collecting tacks or iron screws, on work bench or floors, separating brass from iron, for small electric generators for telephone work, in electric measuring instruments, also to detect copper and brass material from copper and brass-coated iron.

Electro-Magnetism. If a current of electricity is passed through a wire, the wire will be found to act like a magnet. If a compass needle is brought close to the wire, it will set itself across the wire, showing that the direction of the lines of force is around the conductor. If the field around the conductor is explored with a compass, it will be found that the lines of force exist as circles about the conductor, as represented in Figure 8. If the current in the conductor is reversed, the direction of pointing of the compass will reverse, showing that the direction of the lines of force depends upon the direction of the current through the conductor. If the current in the conductor is increased, it will be noted that the compass needle is acted upon at a greater distance from the wire, or that more iron filings will be attracted, showing that the strength of magnetism depends upon the strength of the current. If the current is shut off, no magnetism remains. This is what is called electro-magnetism; that is, magnetism depending upon the flow of electric current.

Direction of Current and Magnetism. From what has been said, it can be seen that there is a definite relation between the direction of current in the coil and the direction of magnetism. This relation can always be determined by applying what is called the **Screw Rule**. The **Screw Rule** is stated as follows: **Turn a right-hand screw so that the screw travels with the current, then the direction of turning shows the direction of wrapping of lines of force.**

Let the left-hand circle in Figure 10 represent the end of a conductor carrying current away from the reader. Apply the Screw Rule to the left-hand conductor. The screw must be turned clockwise (same as the movement of the hands on a clock) in order to have the screw travel away from the reader.

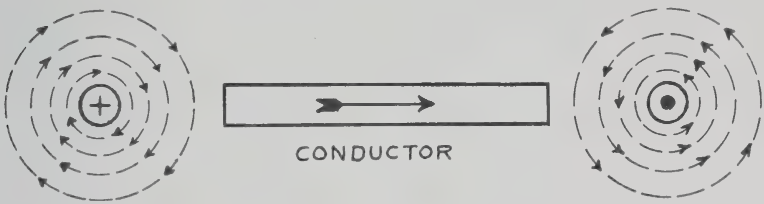


Figure 10—Sketch Showing Direction of Current in a Conductor and Direction of Lines of Force

The lines of force then wrap clockwise around the wire as indicated. The direction of current in the conductor is represented by a dot or a cross. The dot can be thought of as the point of an arrow coming towards the observer, while the cross represents the crossed feathers on the tail of the arrow, as it goes away from the observer. The dot then represents current coming towards the reader, while the cross represents current going away from the reader.

The left-hand circle of Figure 10 tells the story, while the right-hand circle represents conditions for a conductor carrying current towards the reader, or the same conductor viewed from the other end.

Electro-Magnets. If it is desired to have a stronger magnetic field, in a given space, it can be produced by winding the wire in the form of a coil. The magnetism that existed, all along the wire, is thus concentrated within the coil. Such a coil is represented in Figure 11. Instead of the lines of

force existing about each turn of wire separately, they combine so as to link through the entire coil, giving a north pole at one end and a south pole at the other. As air is a poor conductor of lines of force, the magnetic field will not be so strong as it will be if an iron core is placed within the coil. If the iron core is U-shaped, so as to give almost a complete iron path for the magnetism, the magnetic field will be still stronger. The iron used for this purpose should be of good magnetic quality, such

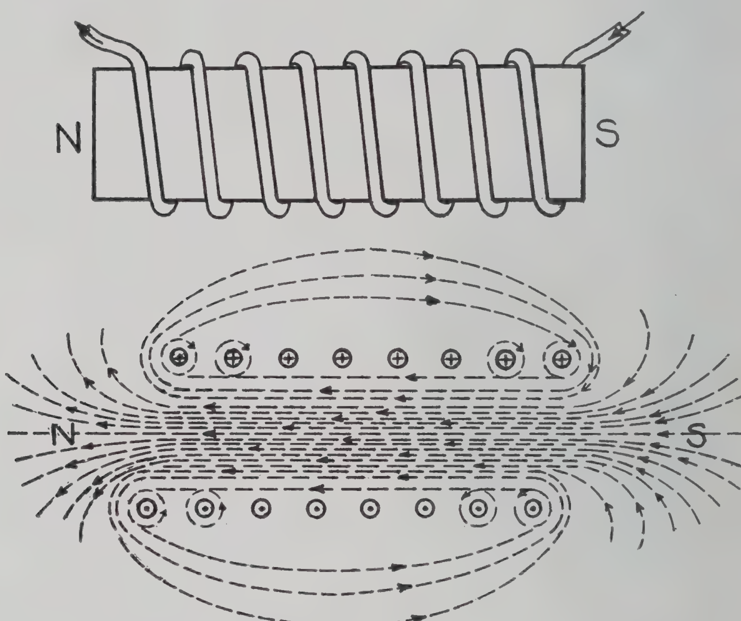


Figure 11—Field of Force About a Coil Carrying Current

Upper Diagram Represents the Coil. Lower Diagram Represents a Section of the Coil Showing Direction of Current and Lines of Force

as soft steel or wrought iron, because with such material the magnetic field will be the strongest.

If the current is varied, the strength of the magnet will be found to vary, in about the same manner as the current, while changing the number of turns will also change the strength of the magnet. In other words, the **strength of an electro-magnet**

depends upon the product of Amperes* and turns of wire. If the product of amperes and turns is the same, the strength of the magnet will be the same, if other factors are not changed. That is, with a given size coil and core, 100 turns and 1 ampere will give the same strength of magnet as 1 turn and 100 amperes, or 2 turns and 50 amperes, or 10 turns and 10 amperes.

If the strength of the magnet were to be measured accurately, it would be found that if we keep the number of turns the same and increase the current, the strength of the magnet would not increase exactly in proportion to the current, and finally a

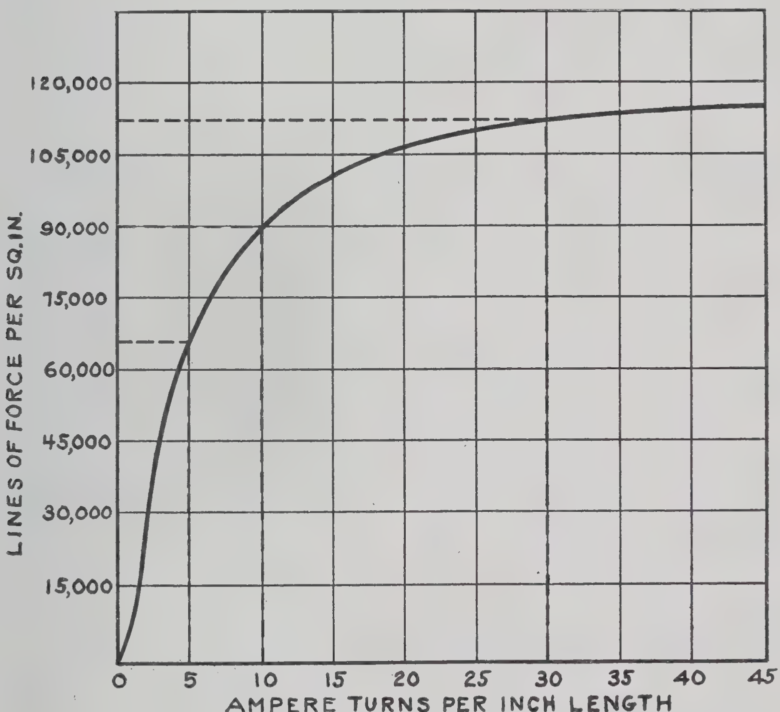


Figure 12—Magnetization Curve for Soft Sheet Iron

point would be reached where further increase in the amount of current would not increase the strength of the magnet to any appreciable extent. That is, a point is reached where the

*The ampere is the unit of electric current, and will be fully discussed in the next lesson.

iron is **Saturated** with lines of force. This is called the **Saturation Point** of the iron. Poor magnetic iron has a low saturation point, while good magnetic iron has a high saturation point. The relation between the magnetism (number of lines of force) and the ampere-turns is shown in the form of a curve, as in Figure 12. The curve can be read as follows:

Find any magnetizing force, say 5 ampere-turns; run up vertically to the curve and then horizontally, following the dotted line; the corresponding number of lines of force per square inch is found to be 67,000. For 10 empere-turns the number of lines of force is found to be 90,000. For 30 ampere-turns the iron is saturated, and increasing the ampere-turns beyond this point does not increase the magnetism.

Magnetic Materials. As has been stated, different grades of iron have different magnetic qualities. Cast iron, for example, is very poor as compared with wrought iron or steel. These facts are shown in the following abbreviated table.*

PRACTICAL WORKING DENSITIES AND LIMIT OF MAGNETIZATION

Material	Practical Working Density		Practical Limit of Magnetization		Absolute Saturation	
	Lines per sq. in.	Lines per sq. cm.	Lines per sq. in.	Lines per sq. cm.	Lines per sq. in.	Lines per sq. cm.
Wrought iron	90,000	14,000	105,000	16,300	130,000	20,200
Cast steel	85,000	13,200	100,000	15,500	127,500	19,800
Mitis iron	80,000	12,400	95,000	14,750	122,500	19,000
Cast iron, 6.5% Al	45,000	7,000	55,000	8,500	87,500	13,500
Cast iron, ordinary	40,000	6,200	50,000	7,750	77,500	12,000

Permeability. By permeability of magnetic material is meant its ability, as compared with air, to conduct lines of force. The equation for permeability can be written as follows:

$$\text{Permeability} = \frac{\text{Number of Lines of Force per unit area in material}}{\text{Number of Lines of Force per unit area in air}}$$

The permeability of a given material is not the same under all conditions. When the amount of magnetism in it is small, the

*Abridged table from Dynamo Electric Machinery by A. Wiener.

permeability is high; that is, a given increase in magnetizing force (ampere-turns) will make a large increase in magnetism, whereas, if the material is highly magnetized, its permeability is low; that is, a given increase in ampere-turns will increase the magnetism but a small amount.

This is shown by the magnetization curve of a piece of sheet iron, as given in Figure 12.

The following table* gives an excellent idea of the variation of permeability, with the material and with the flux density.

MAGNETISM—PERMEABILITY

Density of Magnetization		Permeability			
Lines per sq. in.	Lines per sq. cm.	Annealed Wrt. Iron	Commercial Wrt. Iron	Gray Cast Iron	Ordinary Cast Iron
20,000	3,100	2,600	1,800	850	650
30,000	4,650	3,000	2,100	600	770
40,000	6,200	2,900	2,130	250	770
50,000	7,750	2,650	2,050	110	700
80,000	12,400	1,200	1,250	20	200
100,000	15,500	360	500	9	50
120,000	18,600	80	150	----	----
140,000	21,700	15	75	----	----

Unit of Magnet Strength. Magnetic strength is measured in the number of lines of force in a unit area or space. The Unit Magnetic Pole has **One Line of Force per square centimeter.**** The strength of a magnet is given usually in lines of force per square centimeter or lines of force per square inch.

Law of Magnetism. There is a definite relation between the magnetic flux (lines of force), the magnetizing force (ampere-turns), and the quality of the magnetic circuit. This may be stated as follows:

$$\text{Number of Lines of Force} = \frac{\text{Magnetizing force}}{\dagger\ \text{Reluctance of the magnetic circuit}}$$

*Table abbreviated from a table in "Dynamo Electric Machines," by A. Wiener.

**1 inch=2.54 centimeters.

1 sq. inch=6.45 square centimeters.

†Reluctance means resistance offered to the flow of magnetism. This depends upon quality of material, length of magnetic circuit, joints in the metal, and air gaps.

Numerical values can be assigned to all of these quantities in each case, and that is how the designer proceeds.

Design of Magnets. The complete theory of magnetism has been worked out so accurately that a designer can design electromagnets for any purpose, and the magnet built according to the calculations will perform its duty almost exactly as intended.

Force Acting Between Magnets. The force acting between magnets is proportional to the product of the strength of the two poles divided by the square of the distance between them. That is

$$\text{Force Acting} = \frac{\text{Strength of magnet m x strength of magnet m}'}{\text{Distance}^2}$$

Thus, a magnet of 1 line of force placed 1 centimeter away from a similar magnet is repelled with a force of 1 dyne.* $F = \frac{1x1}{1} = 1$

If the strength of each pole is doubled, then $F = \frac{2x2}{1} = 4$ dynes.

If the magnets used in the first case are placed 2 centimeters apart then $F = \frac{1x1}{4} = \frac{1}{4}$ dyne.

Hysteresis Loss. If the magnetism in a metal is rapidly reversed, the metal will heat up. There are two reasons for this; one is that currents of electricity, called **Eddy currents,** are set up in the iron, and the other cause is that there is friction between the molecules and this represents a certain energy loss, known as the **Hysteresis loss.** This loss takes place in rapidly rotating armatures of motors and generators. Soft steel has lower hysteresis loss than hard steel. Not all of the magnetism set up in a coil passes out through the pole faces.

---

*A very small unit of force.

Magnetic Leakage. The flux that leaks out or passes through parts other than the pole face is called the **leakage flux** and may be quite an item in magnet design. An allowance must be made for magnetic leakage. For small dynamos the leakage is about half of the total flux. The old Edison bi-polar dynamo had a very large magnetic leakage. The more modern dynamos have very much less.

Non-Magnetic Windings. It is sometimes desirable to wind a coil of wire so that it will have no magnetic effect. This can be accomplished by winding the wire double, as shown in Figure 13. The magnetizing effect is neutralized by the current flowing in opposite directions about the coil. This method is commonly used in electrical measuring instruments in which non-magnetic effect must be secured.

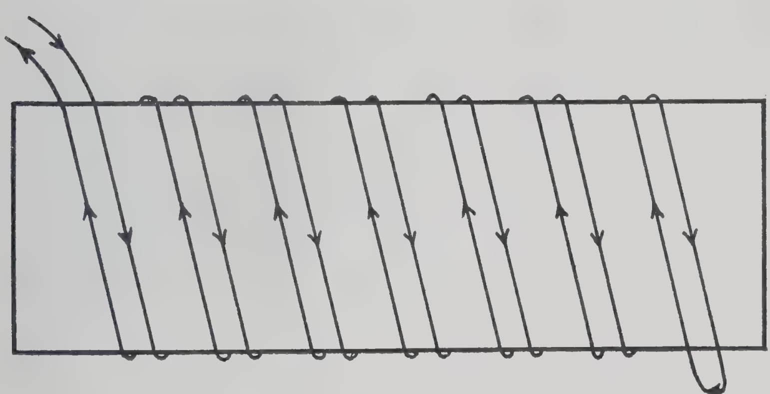


Figure 13—Non-Magnetic Winding Consisting of Double Winding on a Cardboard Form

Forms of Electro Magnets. Electro-magnets are made in many forms, depending upon the use to which they are to be put. Figure 14 shows several forms. Electro-magnets are made in all sizes, from the smallest, about ½ inch across, to the largest lifting-magnets, four or five feet in diameter.

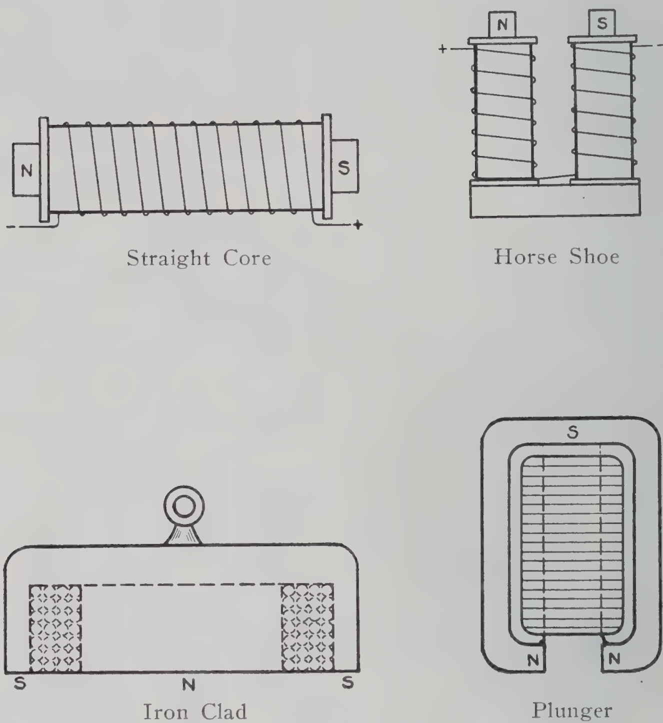


Figure 14—Several Forms or Types of Magnets.

Uses of Electro Magnets. Electro-magnets in some form are used in almost all electrical apparatus. The electric door-bell, the telephone, the telegraph-sounder, the motor and generator, the magnetic separator, lifting magnets, transformers, arc lamps, measuring instruments, all depend upon electro magnets for their operation.

Figure 15—An Electro-Magnet with a Load of Nails. Note Nails Above the Magnet. Picture One-Quarter Size

Electric Bell. In order to understand better the subject of electro-magnets, it will be well to understand a few of their practical applications. Of these, the electric door-bell is probably the most common. The arrangement of the parts and the electrical connections are shown in Figure 16. When the circuit is closed by pressing the button, current passes through the circuit and through the winding of the magnet.

The magnet attracts its keeper K, and, as the keeper moves towards the magnet, the electric circuit is opened at the contact points C, thus stopping the current, the magnet loses its magnetism, and the keeper is drawn back by the spring. This

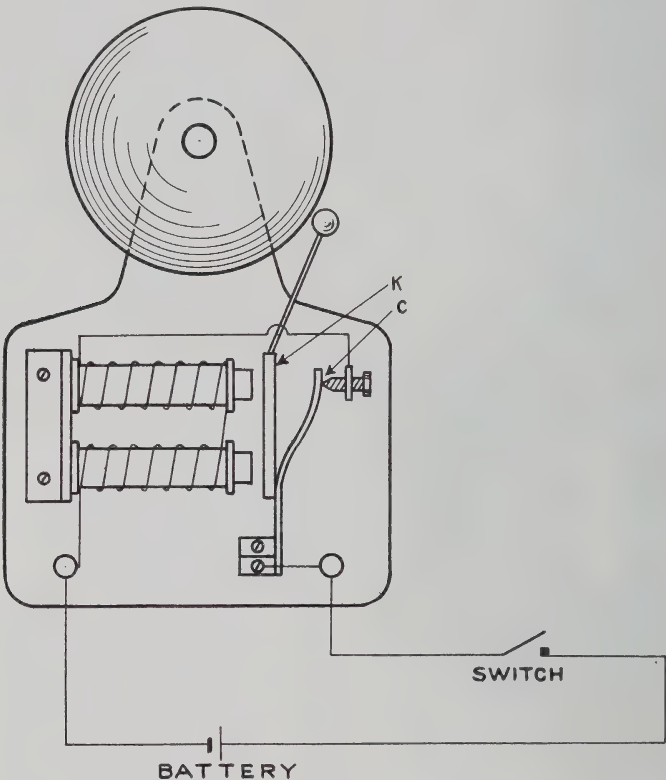


Figure 16—Diagram of an Electric Bell

closes the circuit again at C and the same process continues, causing the clapper attached to the keeper to vibrate as long as the circuit is closed.

Telephone Receiver. The telephone receiver contains both a permanent and an electro-magnet arranged as shown in Figure 17. The core on which the winding is placed is a small permanent magnet. Changes in the current in the

coil strengthen or weaken this permanent magnet, causing its pull on the sheet iron diaphragm D to vary, thus causing the diaphragm to vibrate with the changes in current. The changes in the current passing through the receiver are caused by the sound given to the telephone transmitter at the other end of the line.

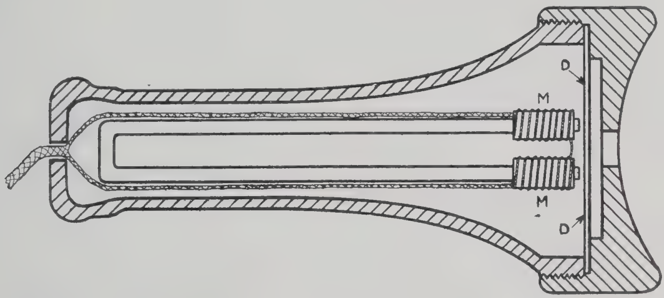


Figure 17—Telephone Receiver A U Shaped Permanent Magnet with Windings on the Poles, and an Iron Diaphragm Close to the Pole Faces

Telegraph Sounder. The telegraph sounder consists of an electro-magnet with its keeper and a bar attached that strikes an anvil, as shown in Figure 18. The circuit of the sounder is opened and closed by a switch, called the telegraph-

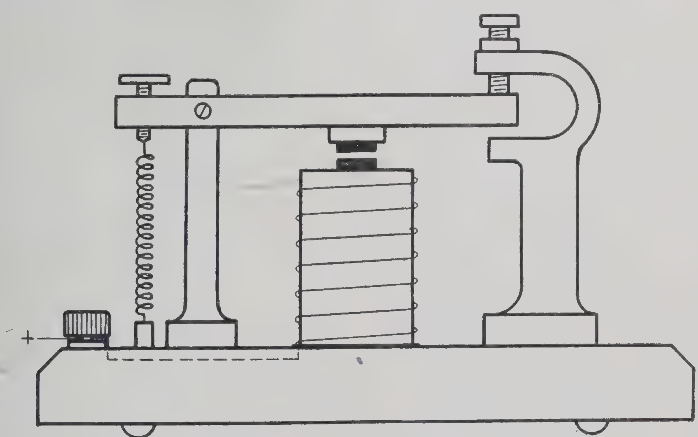


Figure 18—A Telegraph Sounder

er's key. At the instant the circuit is closed the keeper is drawn down and the bar strikes the anvil; when the circuit is opened,

the keeper is released and the bar strikes the back stop. If the key is closed for the shortest interval, the sounder makes a short click called a "dot"; if the key is held closed for three times that time, the interval between the striking of the bar on the anvil and on the stop is correspondingly greater, and a "dash" is produced. The entire alphabet is produced by combinations of "dots" and "dashes." Below is given the International Code.

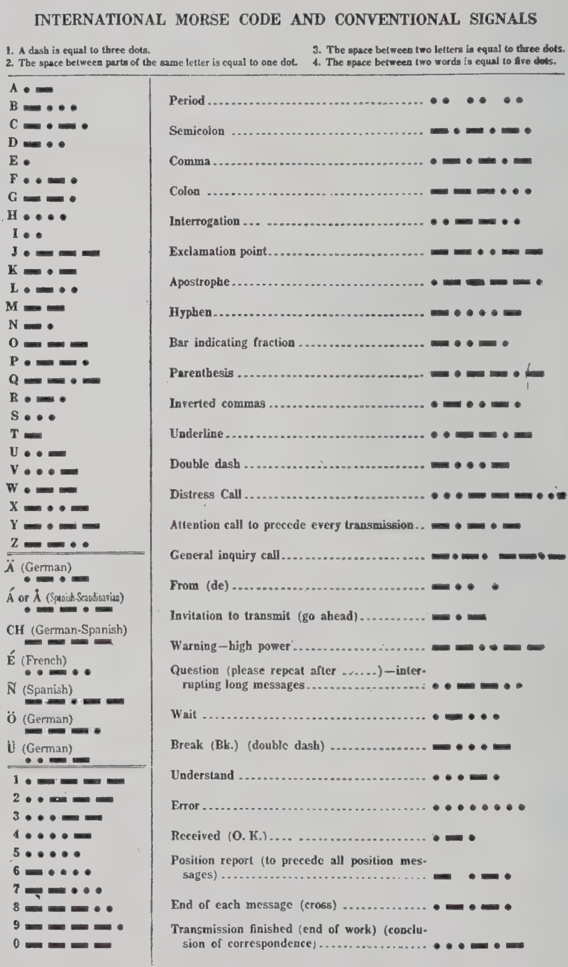


Figure 19—The International Code. This is the Telegraph Code now used Universally in Radio Telegraphy

The Direct Current Motor and Generator* The direct current motor and generator are identical in construction; the difference is in the manner of use. Both depend upon electro-magnets for their operation. In the motor, current is delivered to the machine and it develops mechanical energy, while in the generator the machine is driven by an engine or water-wheel and it develops electrical energy. Figure 20 shows an old form known as the Edison Bi-Polar. These machines are made with almost any even number of poles, as 2, 4, 6, 8, 10, 12, 14, 16, etc. The larger machines have the larger number

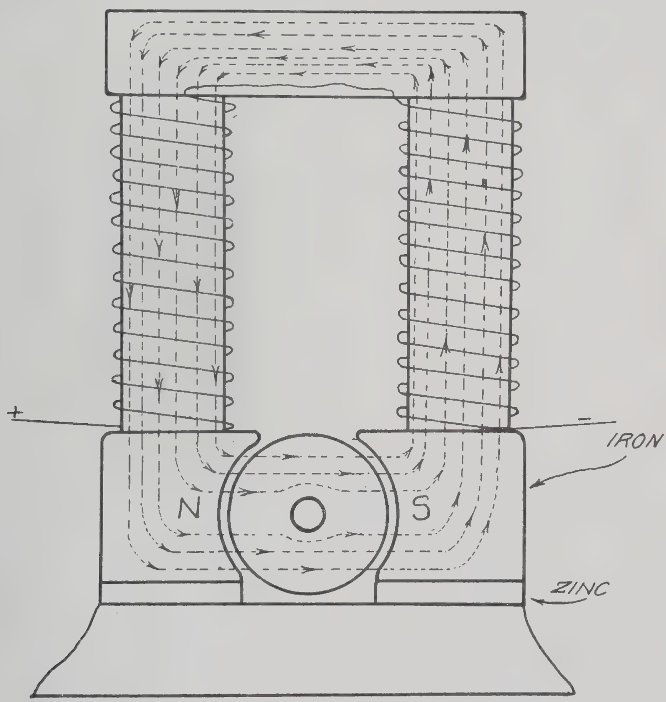


Figure 20—Sketch of An Old Type of Dynamo, Indicating Path of Lines of Force

*A more detailed exxplanation of these machines will be given in later lessons.

of poles. Figure 21 shows diagrammatically the arrangement of the magnetic circuit of a 6 pole dynamo.

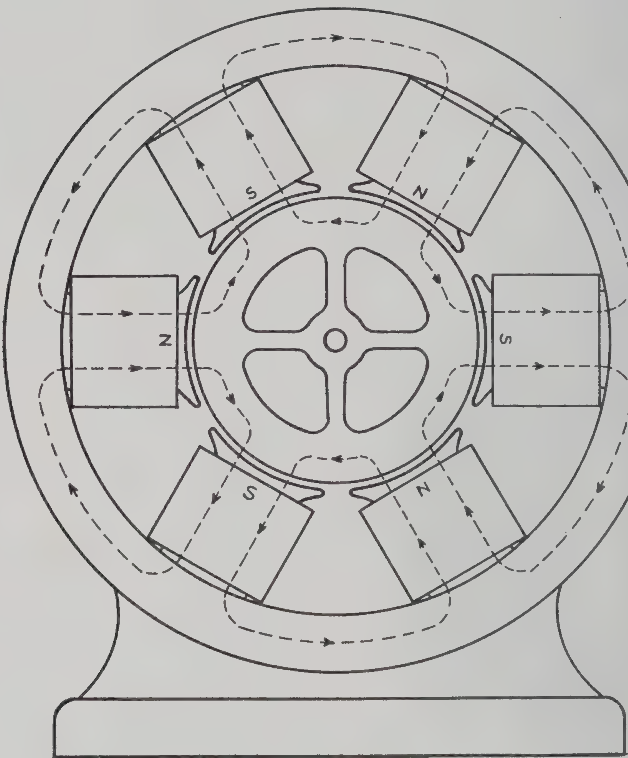


Figure 21—Diagram of the Magnetic Circuit of a Modern Six Pole Dynamo

Magnetic Separator. The magnetic separator is a device for separating magnetic from non magnetic material. For example, in mining, pieces of drills, picks, bolts, spikes, etc., are often found in with the ore, and if these pieces of metal should get into the crusher they would do much damage. The material is passed by a traveling belt over a set of magnetic pulleys, as shown in Figure 22, and all magnetic material is thus removed. These separators are used in ore mills, flour mills, cement mills, and similar places.

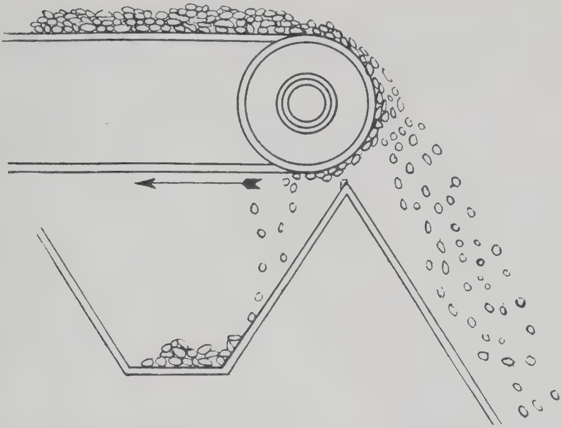


Figure 22—Illustrating the Operation of the Magnetic Separator Pulley. Non-Magnetic Material is Projected Beyond the Pulley, while Magnetic Material is Held in Contact with the Conveyor Belt Until the Latter Passes Under the Pulley

Lifting Magnets. One of the excellent applications of electro-magnets is the Lifting Magnet. A magnet constructed as shown in Figures 23, 24 and 25 is attached to a hoist or crane and lowered so as to touch the magnetic material to be lifted; the current is turned on, the load attracted, and the crane then transfers it to the desired place. The current is turned off and the load is dropped where desired without having been touched by hand. Such large magnets are used in foundries, steel mills,

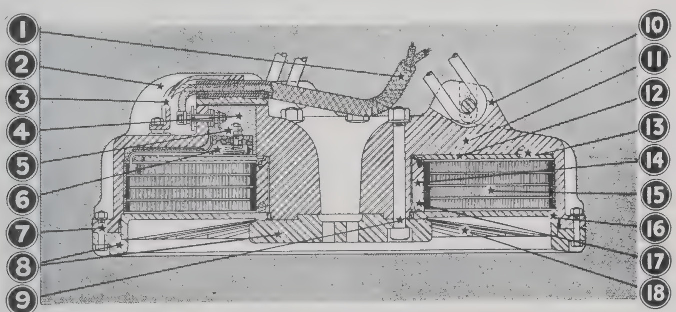


Figure 23—Cross Sectional View of a Lifting Magnet

1—Wires to Coil
2—Flange
3—Steel Cover Over Coil Terminals
4—Terminal Cavity
5—Terminal Stud
6—Wire from Coil to Stud
7—Bolt
8—Pole Shoes
9—Bolt
10—Lug for Chain
11—Steel Magnet Case
12—Top of Coil Spool
13—Dowel
14—Core of Spool
15—Coil of Strap Copper
16—Manganese Steel Shield
17—Tapped Hole
18—Heavy Ribs on Shield

machine shops, warehouses, and can be used anywhere for handling magnetic material. The following statement illustrates the advantage of lifting magnets in handling pig iron:

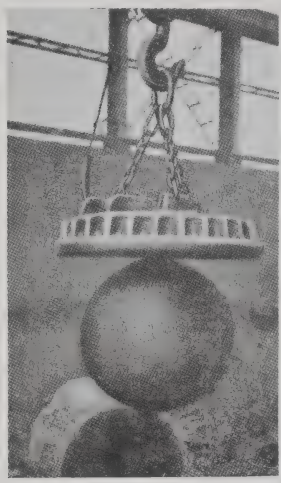


Figure 24—A Lifing Magnet with a 15-ton Skull Cracker Ball.

"ELECTRICITY SAVES THE OWNERS of the great lake steamer 'Cicoa' $500 every time the boat is loaded or unloaded. The steamer carries 4,000,000 pounds of pig iron and with it her own lifting-magnet as a substitute for longshoremen. Electricity energizes the coils of the lifting-magnet when it is lowered into the hold and causes the pigs of iron to stick to the magnet. When it is hoisted out of the depths of the ship a ton of pig iron comes with it. Cutting off the current releases the load of iron and drops it in cars on the wharf. It costs but $100 to load or unload the vessel, a task which it would cose $600 to perform with a crew of longshoremen."

The following abbreviated table will give a good idea of the proportion of a large lifting-magnet and of what it can lift. Figures 24 and 25 shows such a magnet in use.

CAPACITY RATINGS OF NEW HIGH DUTY MAGNETS
Cutler-Hammer Company—Milwaukee

Magnet Size	Net Weight Pounds	D. C. Current Requirement	Approximate Lifting Capacity in Pounds*	Dimensions Three-Point Chain Suspension		Adaptation
				Head Room Required	Outside Diam. of Magnet	
36 in.	1,800	26 Amps. at 220 Volts	1,000 to 1,400	42 in.	36 in.	For general service in handling pig iron, scrap, etc., where a large capacity is not required. Sometimes used with locomotive cranes.
52 in.	5,200	50 Amps. at 220 Volts	2,500 to 2,800	50 in.	52 in.	Most popular for general work. Used extensively in open hearth steel plants for handling stock.
62 in.	7,500	72 Amps. at 220 Volts	4,000 to 4,500	56 in.	62½ in.	Used where a large tonnage must be handled.

*The lifting capacity ratings are very conservative averages based on handling pig iron, bloom and axle butts, crop ends of rails and billets, miscellaneous scrap, and similar material.

With large single pieces such as castings, skull-crackers, balls, etc., the lifting capacity is many times greater, becoming, for example, 60,000 pounds in the case of the 62-inch magnet.

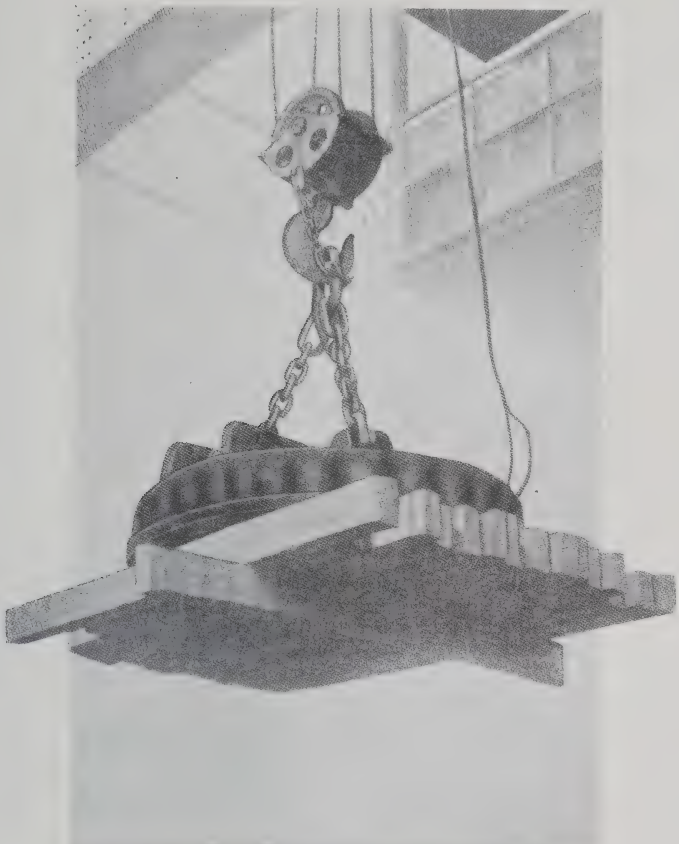


Figure 25—A 62-inch Lifting Magnet, Made by The Cutler-Hammer Co., Milwaukee, as Used in a Steel Mill with a Load of Steel Billets, Total Weight 8925 Pounds

Lifting Power of Magnets. The lifting power of a magnet depends upon two factors—the size, that is area of the poles, and the magnetic flux density.

The equation for pounds pull of a magnet is

$$\text{Pounds Pull} = \frac{\overline{\text{Area} \times \text{Flux Density}}^{\,2}}{72{,}134{,}000}$$

Note. The illustrations and data on lifting magnets and magnetic separators are used through the courtesy of The Cutler-Hammer Co., Milwaukee.

In this expression the area is in square inches and the flux density in lines of force per square inch. The pull for each square inch of pole surface of a good magnet is between 100 and 200 lbs., as can be seen by using the equation.

$$\text{Pounds Pull} = \frac{1 \text{ (sq. in.)} \times 100{,}000 \times 100{,}000}{72{,}134{,}000}$$
$$= 138$$

*MAXIMUM PULL PER SQUARE INCH OF CORE FOR SOLE-NOIDS WITH OPEN MAGNETIC CIRCUIT.

Length coil inches	Lengh plunger inches	Area core sq. in.	Total amp. turns	Amp. turns per in.	Max. pull lb. per sq. in.	Lb. per sq. in. per 1000 amp. turn per inch.
6	Long	1	15,000	2,500	22.4	9.0
10	10	2.76	40,000	4,000	40.2	10.0
12	Long	1	11,200	930	8.75	9.4
18	36	1	18,200	1,010	9.8	9.7

Magnets in Surgery. The electro-magnet has been used for many years to remove bits of steel and iron from the eyes of workmen and from the wounds of soldiers. The following clipping from the Electrical World shows how valuable it was in the recent war:

Electro-magnets for War Surgery.—*At the recent meeting of the French Academy of Medicine Dr. A. Dastre explained the uses to which a powerful electro-magnet could be put in removing shrapnel splinters and steel-jacketed bullets from wounded soldiers. It is claimed that an electro-magnet used by Professor Rolet drew shrapnel fragments to the surface from a depth of 6 inches, and bullets from a depth of 2¼ inches.*

Meters† The parts of a watt-hour meter are shown in Figure 26. It will be noticed that this is essentially a motor and depends upon electro-magnets for its operation.

Ammeters and Voltmeters, Wattmeters, in fact, nearly all of the electrical measuring instruments, depend upon permanent and electro-magnets for their operation. Figure 27 shows the parts of a Weston ammeter, switchboard type.

---

*Table abbreviated from Standard Hand-Book Data from Underhill.
†The subject of meters will be covered fully in a later lesson.

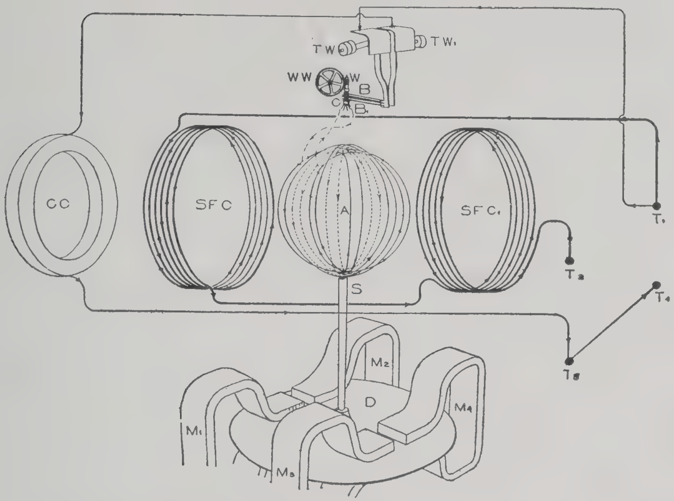


Figure 26—Diagram of a Direct Current Watt-Hour Meter

A—Armature
C—Commutator
D—Disk
M_1 M_2 M_3 M_4—Permanent Magnets
SFC—Field Coils

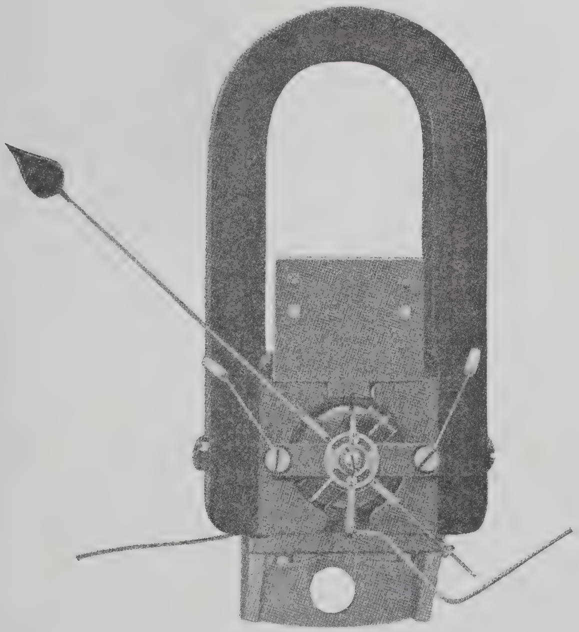


Figure 27—Mechanism of a Weston Measuring Instrument

Alternating Current Magnets. The electro-magnets considered up to this point are supplied with direct current; that is, current flowing continuously in the same direction. Such current produces magnetism continuously in the same direction; that is, one end of a coil will be continuously a North Pole, and the other end a South Pole, unless the direction of the current through the coil is changed.

If an alternating current, that is, a current that continuously changes in value and reverses many times per second, is supplied to a magnet coil, the magnetism will change to correspond to the changes of current. Since iron is attracted by a magnet, regardless of the direction of magnetism, an alternating current magnet will therefore attract iron; but as the current reverses it passes through a zero value, the magnetism likewise, and there is a tendency for an alternating current magnet to drop its load at such time. The result is that the pull of an alternating current magnet fluctuates rapidly and the keeper chatters or hums.

As will be shown in a later lesson, a magnet to be used on alternating current should be provided with a core made up of thin iron strips of iron wire, instead of a solid core, such as is used with direct current magnets.

Uses of Alternating Current Magnets. As might be expected, alternating current magnets are not so extensively used as direct current magnets. Alternating-current meters, alternating current motors, and transformers, all depend upon alternating current electro-magnets.

Effect of Magnetism on Watches. If a good watch is brought near a strong magnet, it will become magnetized, and the effect will be that the watch will run in a very erratic manner. It cannot be regulated. A watch can be tested for magnetism by placing a small compass (needle ½ inch long or less) directly over the balance wheel. If the compass needle moves back and forth, trying to follow the movement of the balance wheel, the watch is magnetized.

The magnetism can be removed easily by one of the following methods:

Pass a string through the ring of the watch and twist the string so that the watch will spin when the watch hangs free. Bring the watch near a permanent magnet or near an electromagnet and allow it to spin, gradually moving the watch out of the magnetic field while it is spinning. The effect is that the magnetism in the watch is rapidly reversed in a weaker and weaker field and is gradually reduced to zero.

If alternating current is available, a coil of about 100 turns and carrying from one-half to one ampere can be used. Such a coil is represented in Figure 28. The watch should be placed in the coil and slowly withdrawn to a distance of several feet.

The latter method is the more satisfactory.

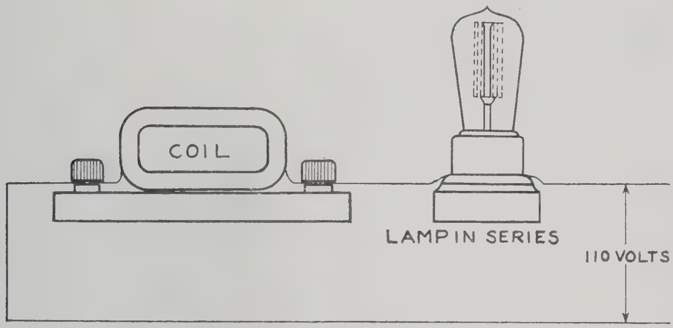


Figure 28—Watch de-Magnetizing Coil

Magnetic Shields. There are no insulators for magnetism. Lines of force pass through glass, porcelain, wood, brass, and in fact all materials. The best protection against magnetism is to surround the article with a good magnetic material, such as iron. The lines of force will then pass through the iron instead of through the enclosed space.

Magnetic shields for watches are made in this way. They consist simply of two iron covers hinged together so that a watch can be placed between them.

Electrical measuring instruments are often made with iron cases, in order that stray magnetic fields will not affect their readings.

Conclusion. The reader will realize that the subject of magnetism is a large one and that volumes could be written on the subjects touched upon briefly in this lesson. It will be found well worth while to consult the list of references given and to study these as much as the reader's requirements will indicate.

SIMPLE EXPERIMENTS

Material Required. The principles of magnetism can be demonstrated in a very satisfactory manner if the following materials are at hand:

1 pane of window glass or card-board 8x10 inches.
1 compass.
1 horse-shoe or bar magnet.
50 feet of insulated wire, No. 10 or larger.
Iron filings.
A rheostat.
A source of direct current of capacity to supply from 10 to 50 amperes.

Experiments. 1. Show direction of Earth's Magnetic Field by aid of the compass.

2. Determine polarity of bar or horse-shoe magnet, using the compass.

3. Place the glass on the permanent magnet, sprinkle on iron filings, tap the glass with a pencil to aid the filings to adjust themselves. Note the direction and position of the lines of force.

4. If two permanent magnets are available (magnets from watt-hour meters or magnetos are very good) show how like poles repel and unlike attract, by suspending one magnet from a thread and bringing the other magnet to it, having first determined the polarity of the magnets as in Experiment 2.

5. Magnetize a steel knitting-needle by stroking one end with the north pole of the magnet and the other end with the south pole of the magnet. Test the needle with a compass, to

show polarity. Suspend the needle from a fine thread. If the magnetism in it is strong, it will set itself in a north and south direction. Break the knitting-needle into several parts and test with a compass, to show that each piece has a North and South Pole.

6. Connect the wire up with the source of direct current and a rheostat. Send current through the wire and place the compass above and below the wire, to show the direction of the lines of force.

Determine the direction of current by using the compass and applying the **Screw Rule.**

Pass the wire through a cardboard and sprinkle iron filings around it, to show lines of force about the conductor.

7. Wind the wire in the form of a large coil with turns 12 inches or more across. Spread out the turns and tie to supporting sticks.

Suspend a large bar magnet in center of coil. Send current through coil and note action of bar magnet.

Reverse direction of current and note effect on magnet.

8. Trace out direction of magnetic field around coil with the compass.

9. Wind the wire in a smaller coil, or better, use smaller wire with a large number of turns, and wind on a cardboard tube. Send current through the coil and test its strength, first without and then with an iron core.

10. If possible, use the magnet to show its lifting power by bringing a few pounds of nails to the magnet. Turn off the current to show how it drops its load.

REFERENCE BOOKS.

Electricity Experimentally and Practically Applied, by Sidney W. Ashe, D. Van Nostrand Co., New York.

Applied Electricity for Practical Men, by Arthur J. Rowland, McGraw-Hill Book Co., New York.

Elements of Electricity and Magnetism, by Franklin and McNutt, McMillan Co., New York.

Elements of Electricity, by Timbie, McMillan Co., New York.

Elements of Electricity and Magnetism, by D. C. and Wm. B. Jackson, McMillan Co., New York.

Solenoids, by Chas. R. Underhill, D. Van Nostrand, New York.

Standard Handbooks of Electrical Engineers, McGraw-Hill Book Co.

QUESTIONS.

Note: These questions are to be answered after the lesson has been studied carefully, and without further reference to the lesson.

1. What is a magnet?

2. How are artificial magnets made?

3. What is an electro-magnet? Explain its construction and principle of operation.

4. Of what importance is the electro-magnet in electrical science?

5. Describe the lifting magnet, construction and use.

6. Explain the difference in magnetic quality of various kinds of iron.

   (b) What material is best for permanent magnets?

   (c) What material is best for electro-magnets?

7. How can a coil be wound so as to have no magnetic effect?

8. What application of electro-magnets are you familiar with, other than those described?

9. A horse-shoe shaped electro-magnet has poles of 100 square inches each. What is the maximum weight that it will lift?

10. If a magnet is made of soft sheet steel and has 15 ampere-turns per inch length what will be the number of lines per force per square inch (See curve Figure 12—Page 15).

INDEX